Evolution of oceanic precipitation anomalies during El Niño Southern Oscillation (ENSO) events of the last two decades

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Summary

The Global Precipitation Climatology Program (GPCP) recently released monthly global precipitation data that allowed an analysis of oceanic precipitation anomalies before, during, and after El Niño Southern Oscillation (ENSO) events of the last two decades. During each ENSO event, a major positive precipitation anomaly was observed in the Central and Eastern Equatorial Pacific, while a major negative precipitation anomaly was observed in the Western Equatorial Pacific and Eastern Equatorial Indian Ocean. These precipitation anomalies co-varied strongly with sea surface temperature of the eastern equatorial Pacific, and may therefore be a good indicator of ENSO events. The precipitation anomaly pattern of 1997-98 differs significantly from previous ENSO events and calls certain aspects of current theories on ENSO into question.

Oceanic precipitation anomalies and their connection with El Niño Southern Oscillation (ENSO) were noted almost a century ago (1). Together with the anomalies of surface wind and sea surface temperature (SST), precipitation anomalies have long been used to characterize ENSO events (2-9). Although the temporal and spatial resolution of ~~surface wind and SST has increased dramatically increased, precipitation data have not~~ yielded comparable detail (10-13) and were not included in recent ENSO studies (14-18). Recently, the Global Precipitation Climatology Program (GPCP) released monthly global precipitation data (2.5° x 2.5°) for the last two decades (19), which significantly increased temporal coverage and spatial resolution of oceanic precipitation data. Here we report the evolution of oceanic precipitation anomalies as revealed from an analysis of the GPCP data set.

During the last two decades, there were two major (1982-83 and 1997-98, SST anomaly > 2°K, east equatorial Pacific) and several minor (1986-87, 1992-93, 1994-95) ENSO events, each characterized both by unusually warm SST east of the international dateline (180°W) and high precipitation in the central and east equatorial Pacific (Figs. 1 and 2). Temporal variability was dominated by an annual cycle of alternating warm-wet and cold-dry belts, and spatial variability was dominated by a warm-wet region to the west and a cold-dry region east of the international dateline (Fig. 1). During each ENSO event, however, the western Pacific warm pool (SST > 29°C) migrated eastward accompanied by an eastward migration of a wet region (PPT > 5 mm d^{-1}) (Figs. 1 and 2). The centers of the wet regions varied significantly between ENSO events (from 180°E to 130°E). Mean precipitation and SST anomalies (Fig. 3 top and bottom) of the central and eastern equatorial Pacific followed a remarkably similar trend, while the mean precipitation anomaly of the western equatorial Pacific ocean (Fig. 3, middle) showed an opposite trend. Therefore, like sea surface temperature anomalies of the eastern equatorial Pacific, oceanic precipitation anomalies of the western, central and eastern equatorial Pacific may also be a good indicator of ENSO events.

There are three major differences between precipitation anomalies of 1997-98 and previous ENSO events. First, in previous ENSO events, the positive precipitation anomaly of the equatorial Pacific was confined to the central region during and before the peak ENSO event (Fig. 2 and 4), while, in 1997-98, the positive precipitation anomaly spread from the central and eastern equatorial Pacific to the South American coast during the ENSO event (Fig. 2 and 5). The predominant theory of ENSO-related atmospheric

circulation suggests that during non-El Niño years, Walker circulation dominates along the equatorial plane with ascending air over the west Pacific, descending air over the east Pacific, easterly wind at the surface, and westerly wind aloft (20). During El Niño years, the Walker circulation split into two cells with ascending air over the central equatorial Pacific, winds toward the central equatorial Pacific at the surface and away from it at altitude, and descending air over both the west and east equatorial Pacific. The cooling of ascending wet air leads to high precipitation. The positive precipitation anomaly of the central equatorial Pacific in 1982-83 and all minor ENSO events (Fig 2) aligns with this scenario, while that of 1997-98 does not. The atmospheric circulation pattern at the equatorial plane could not be deduced from precipitation data alone, but precipitation patterns associated with the 1997-98 ENSO event indicate that air has to be ascending from the entire central and east equatorial Pacific to yield such a precipitation anomaly.

Additionally, there was a negative precipitation anomaly in the central and eastern equatorial Pacific to the north of the main positive anomaly throughout the 1997-98 ENSO event (Fig. 5). In contrast, the negative anomaly in this region did not develop until the end of the 1982-83 ENSO event. This anomaly indicates that there might have been a southward shift in the Hadley Cell throughout the 1997-98 ENSO event.

Finally, while the geographic location of the major positive precipitation anomaly of the Indian Ocean shifts during ENSO events, it occurred primarily in the central equatorial region during the 1982-83 ENSO event (Fig. 4) and in the west equatorial

Indian Ocean during the 1997-98 ENSO event (Fig. 5). This difference indicates that the uniqueness of 1997-98 ENSO event was not limited to the Pacific.

Figure caption

Fig. 1. Time-longitude sections of precipitation (left) and SST (right) from February 1979 to December 1999. Analysis is based on monthly averages for between 6.25°N to 6.25°S for GPCP precipitation and between 5°N and 5°S for Reynolds SST.

Fig. 2. Time-longitude sections of anomalies in precipitation (left) and SST (right) from February 1979 to December 1999. Analysis is based on monthly averages for between 6.25°N to 6.25°S for GPCP precipitation and between 5°N and 5°S for Reynolds SST. Anomalies are relative to monthly climatologies based on data from 1979 to 1999.

Fig. 3. Monthly averaged time series of anomalies in: (A) precipitation for the east equatorial Pacific (6.25°N to 6.25°S and 148.75°W to 88.75°W), (B) SST for the east equatorial Pacific (5°N to 5°S and 150°W to 90°W), and (C) precipitation for the east equatorial Indian and west equatorial Pacific (6.25°N to 6.25°S and 91.25°E, 151.25°E). The precipitation and SST anomalies were calculated after seasonal trends were subtracted.

Fig. 4. Monthly average precipitation (top), precipitation anomaly (middle), and SST anomaly (bottom, in °C) for December 1982. The anomaly is relative to SST climatology, 1979-1999.

Fig. 5. Monthly average precipitation (top), precipitation anomaly (middle), and SST anomaly (bottom, in °C) for December 1997. The anomaly is relative to SST climatology, 1979-1999.

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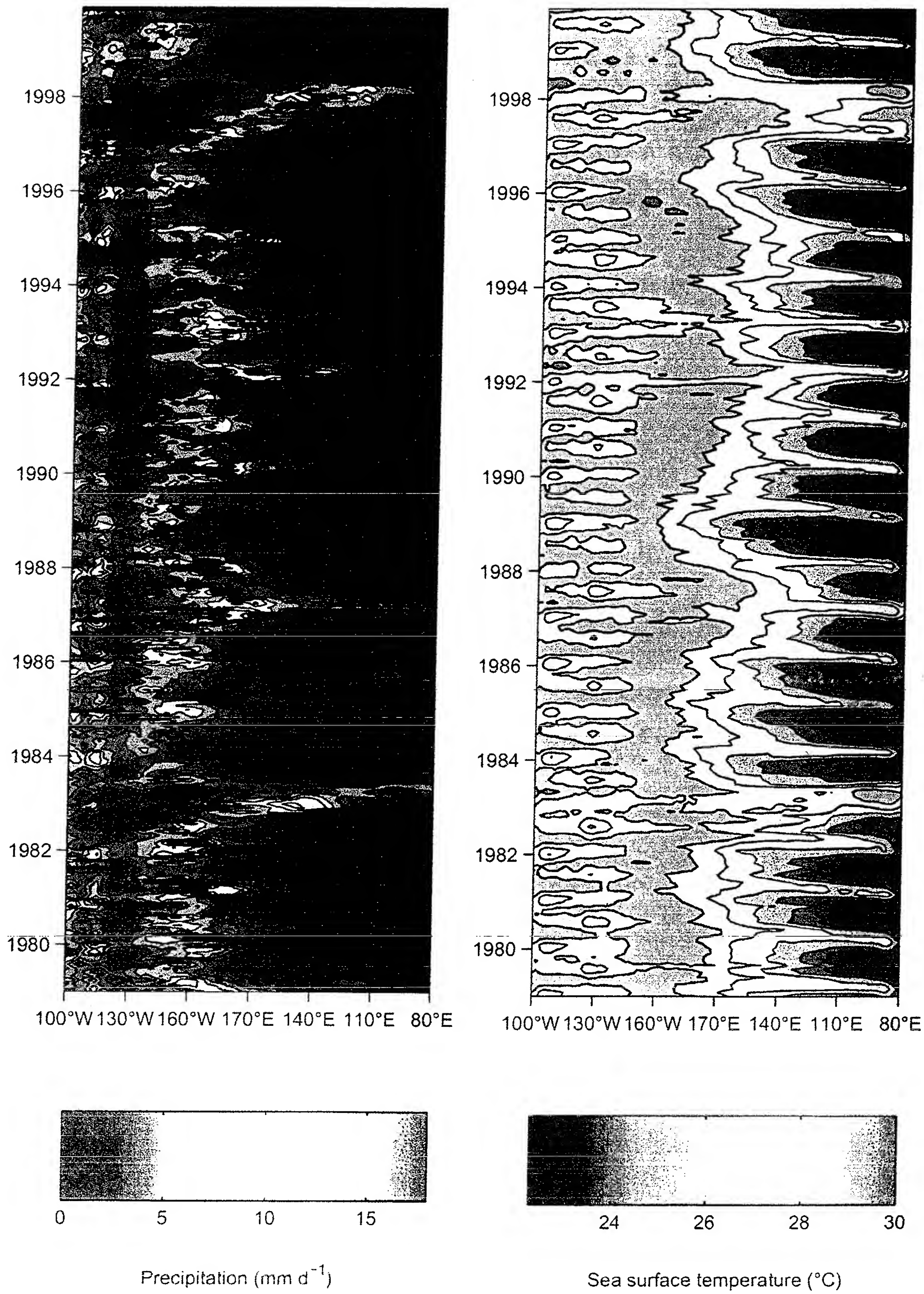
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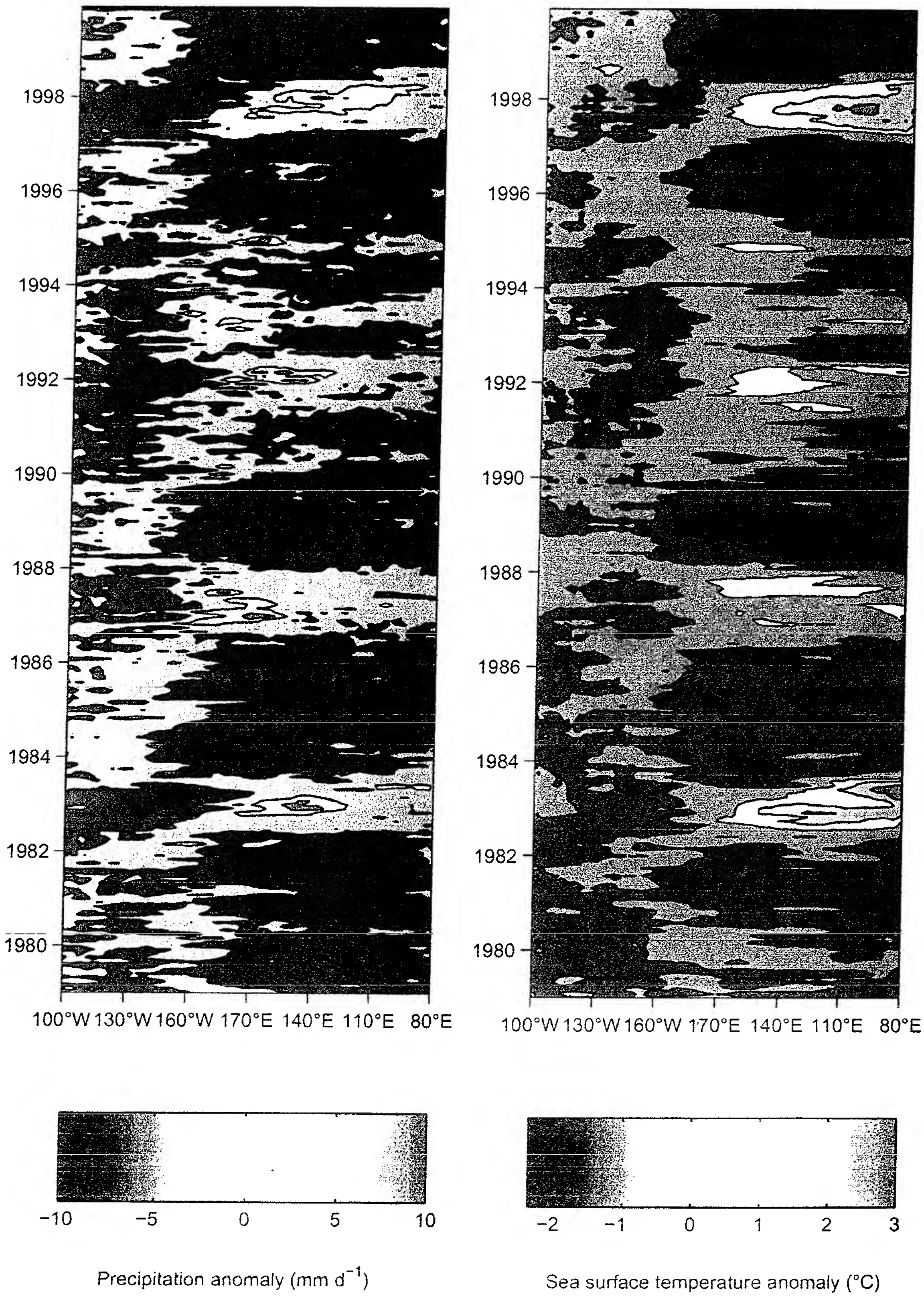
Precipitation (mm d^{-1})
24 26 28 30
Sea surface temperature (°C)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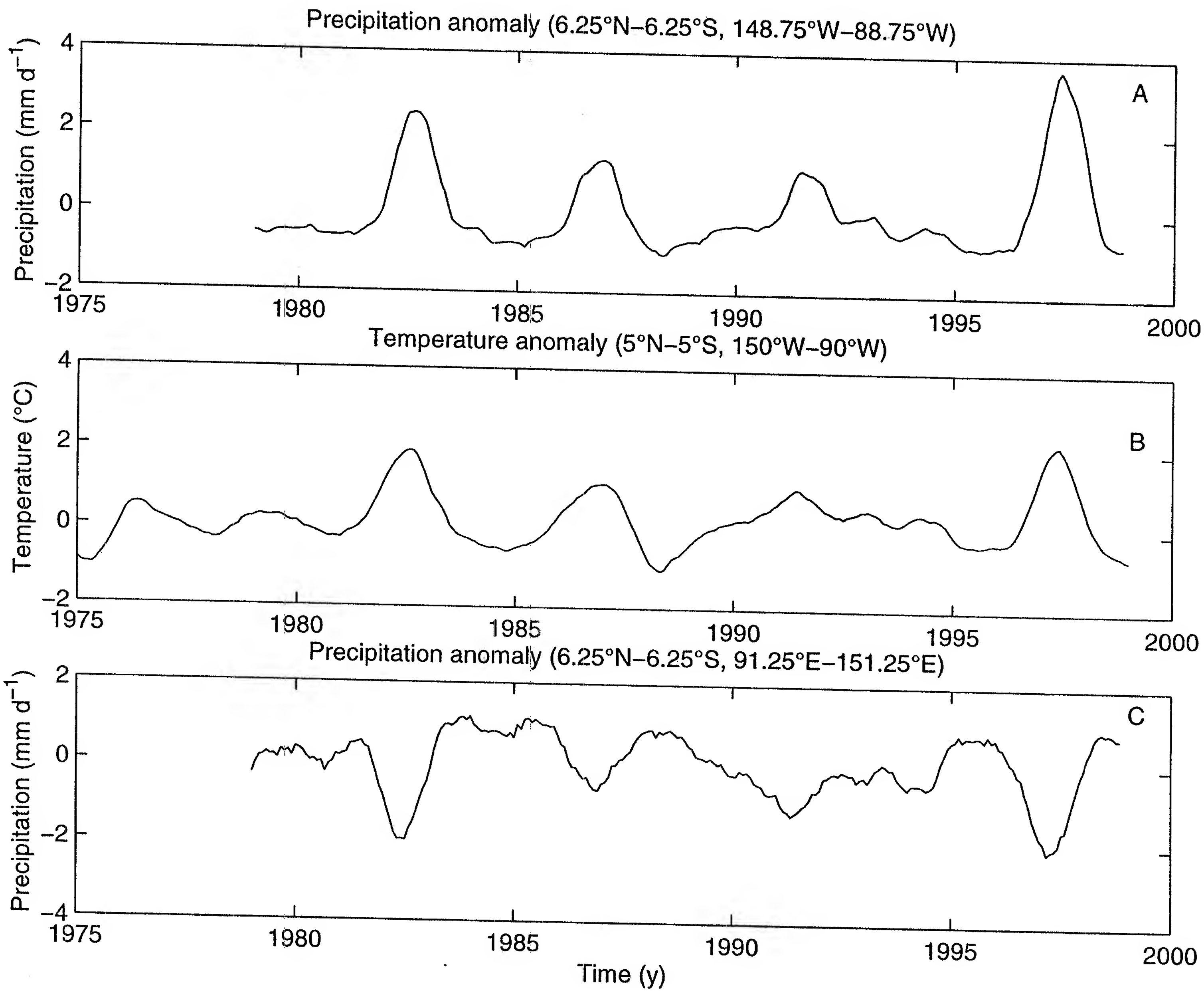
Sea surface temperature anomaly (°C)



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Precipitation (mm d^{-1})
A
Temperature anomaly (5°N–5°S, 150°W–90°W)
Temperature (°C)
B
Precipitation anomaly (6.25°N–6.25°S, 91.25°E–151.25°E)
Precipitation (mm d^{-1})
C
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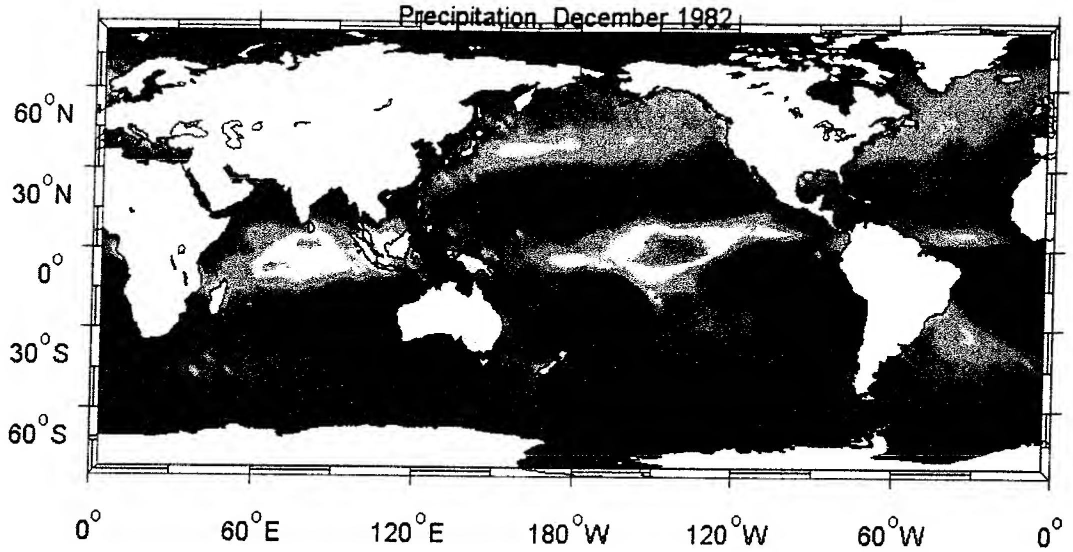
Time (y)


Precipitation, December 1982
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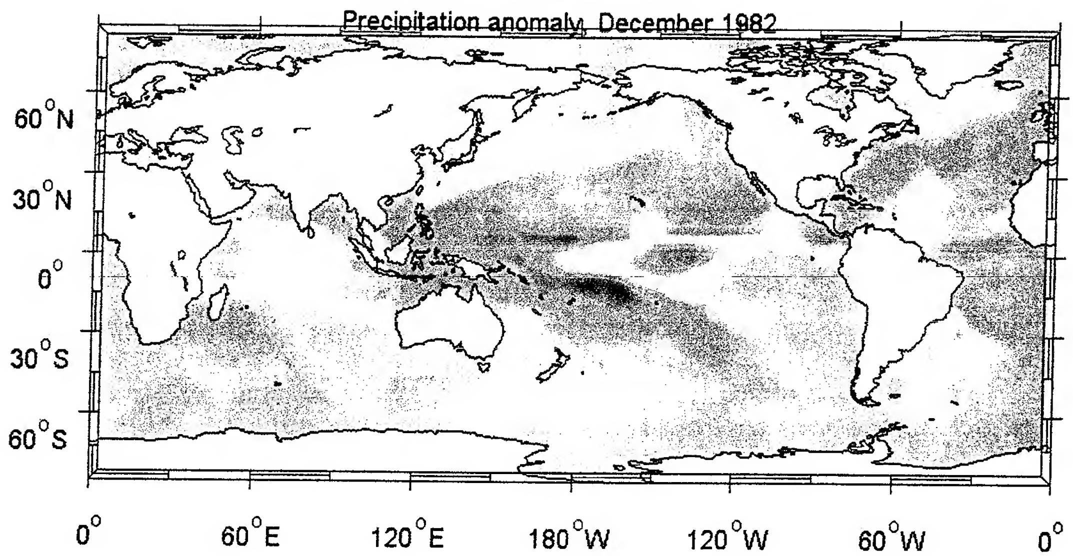
Precipitation anomaly, December 1982
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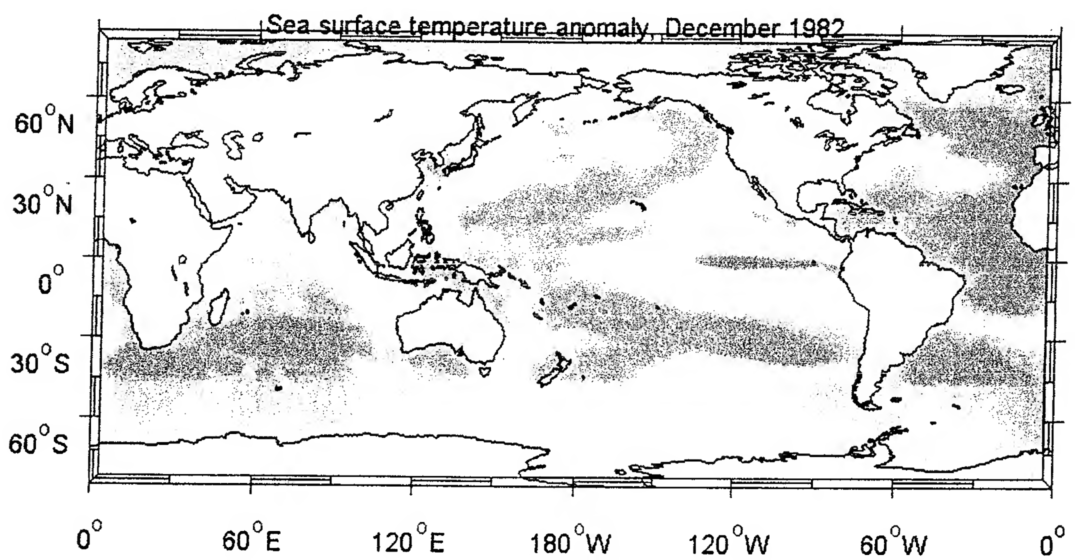
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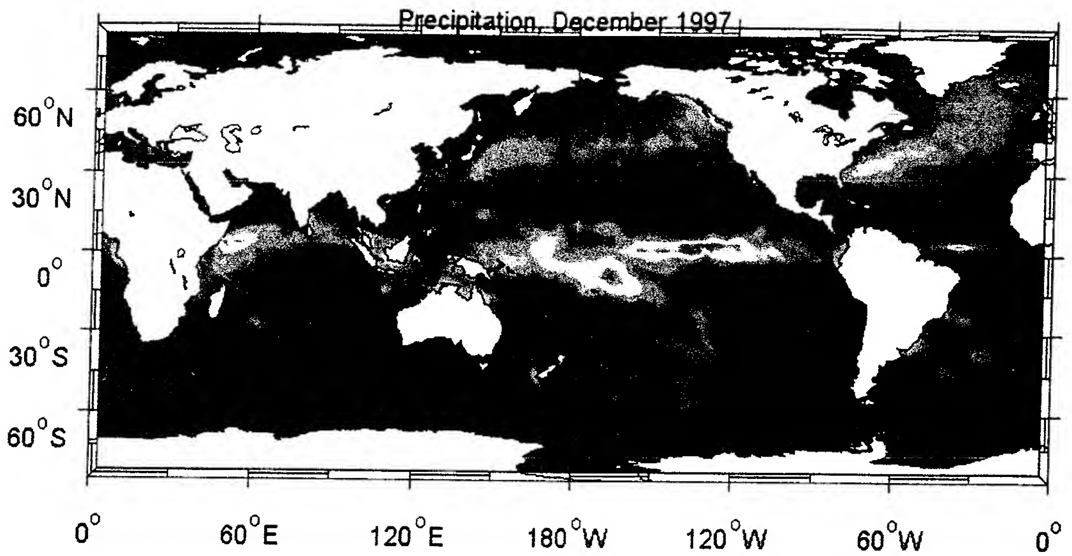
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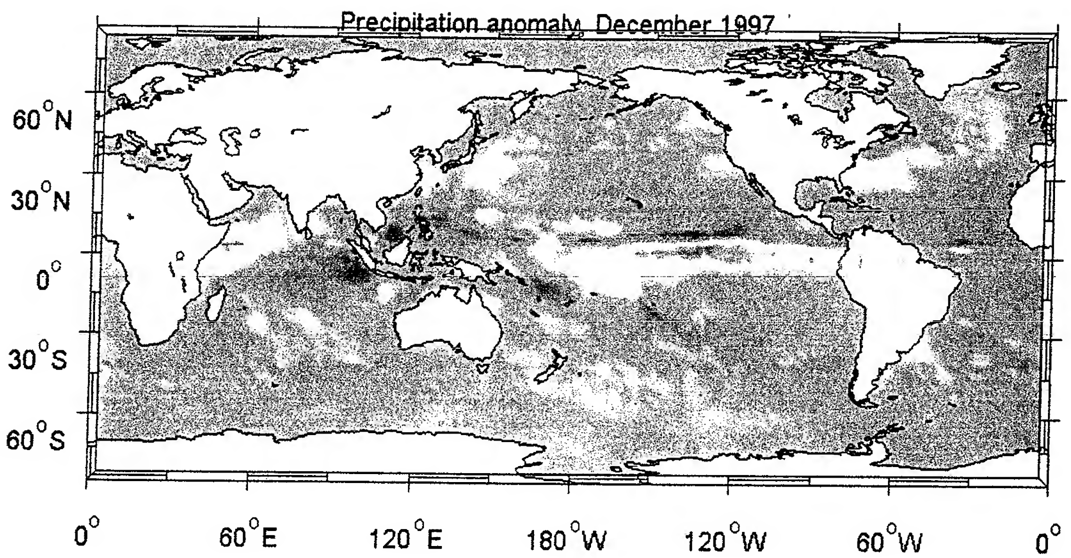
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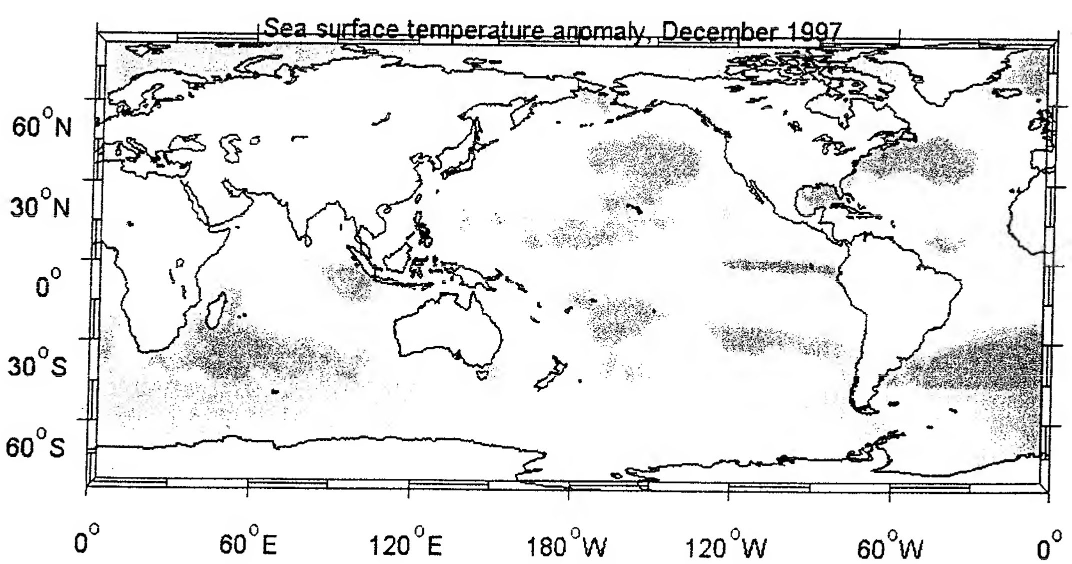
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